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Integrated Optic Modulator and Splitter Damage at 1053nm

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ABSTRACT

We are designing and developing a single mode fiber laser and modulation system for use in an inertial confinement fusion research laser, the National Ignition Facility (NIF). Our fiber and integrated optic oscillator / modulator system generates optical pulses of around 30 nanoseconds duration, at one kilohertz, with up to 500 nanojoules of energy. This is enough to potentially damage some of the single mode fiber and waveguide components.

To test these components, we have built a test system using a diode-pumped Nd:YLF laser, producing 10 microjoules in 120 nanoseconds at 500 hertz. This system has been used to test commercial lithium niobate integrated optic modulators, silica-on-silicon waveguide splitters, lens-coupled dichroic mirror splitters, and other fiber optic components. We present results of damage tests and efforts to improve performance.

Keywords: damage tests, fiber laser, modulator, lithium niobate, fiber optic components,

2. NIF SYSTEM DESIGN

Figure 1 shows the Master Oscillator Room (MOR) optical design. The system is an all single mode fiber and waveguide component design. Optical pulses are generated by a fiber ring oscillator with a Q-switched output pulse ~200 nanoseconds FWHM, operating at 1khz. Energy per pulse is ~50 nanojoules at an operating wavelength of 1053 nanometers. Optical pulses are then phase modulated and chopped to a 30 nanosecond square pulse. Pulses are then amplified and split with a four stage fiber amplifier splitter network to 192 separate signals. Each of the 192 signals are then amplitude modulated and distributed to separate preamplifier modules. Figure 2 shows the calculated MOR system peak power levels used as criteria for the fiber component performance with several of the critical components identified.

With the number of different types of components that were tested, the areas that would likely damage were identified based on the type of component and power level. For example: for fiber connectors (FC-APC), damage can occur from subsurface polishing damage or contamination at high peak powers. Integrated optic splitters can damage at the epoxy at the fiber/chip interface or at the Y-junctions. Lithium niobate modulators suffer photorefractive damage at high average power, causing extinction ratio degradation or damage at the epoxy interface at lower peak powers.

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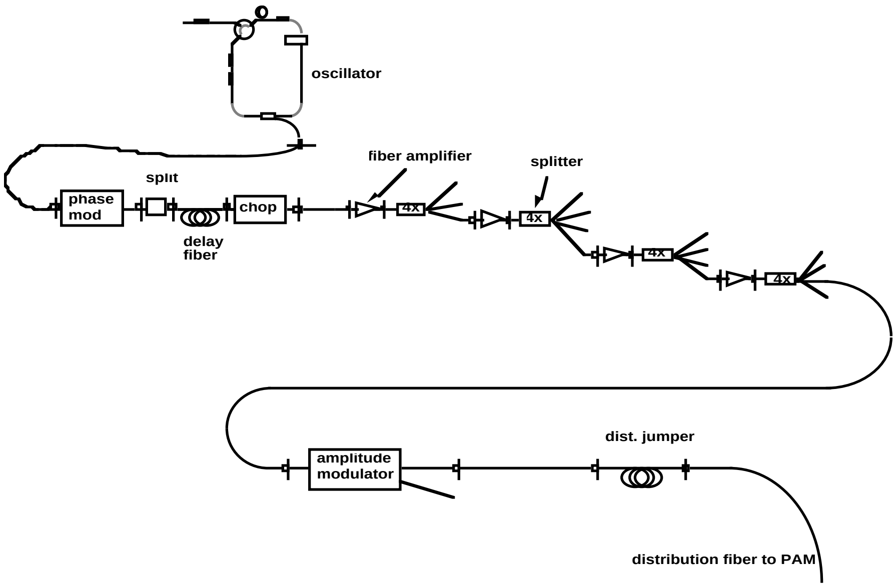


Figure 1

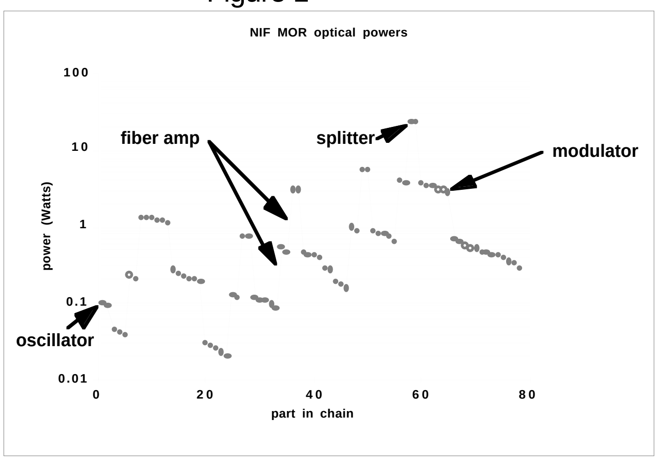


Figure 2

3. LASER DAMAGE TEST SYSTEM

A laser system has been built to damage test the NIF type fiber components. A Spectra-Physics Tightly Folded Resonator (TFR) YLF diode pumped amplifier design was reconfigured as a Q-switched laser at 1053nm (figure 3). The laser has variable feedback control for optimizing output coupling and is Q-switched at 500hz using an electro-optic Pockels cell. The laser produces 10 microjoules in 120 nanoseconds or >80 watts peak power. The output energy stability is good with an RMS dev. of 2.5% or several hours operating time.

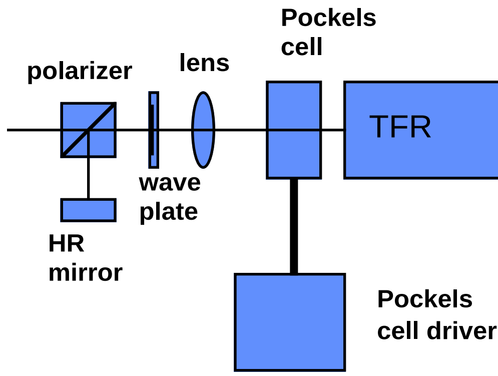


Figure 3

The TFR laser is integrated with damage test system shown in figure 4. The laser pulse is relayed to a fiber launch station where the component to be tested is mounted and aligned. Initial rough alignment of the single mode fiber is completed using a CCD camera system with 12 micron per pixel resolution. Precision alignment is achieved using remote fiber coupling lens control with closed loop feedback. The feedback signal is picked off using a single mode coupler with microbending loss coupling. The incident field distribution is matched to the fiber mode. Maximum fiber coupling >65% has been achieved.

Based on the mode size in the fiber, peak power and fluence can be calculated. The mode field area in our single mode polarization maintaining fiber is ~200 x 10^-9 cm^2. For one watt peak power, in a square 30ns pulse, the intensity is 5.2 MW/cm^2 and the fluence is 0.156J/cm^2. Some components will run at tens of watts peak power, resulting in multiple joules per cm^2 and tens of megawattts per cm^2. We expect energy damage before power damage.

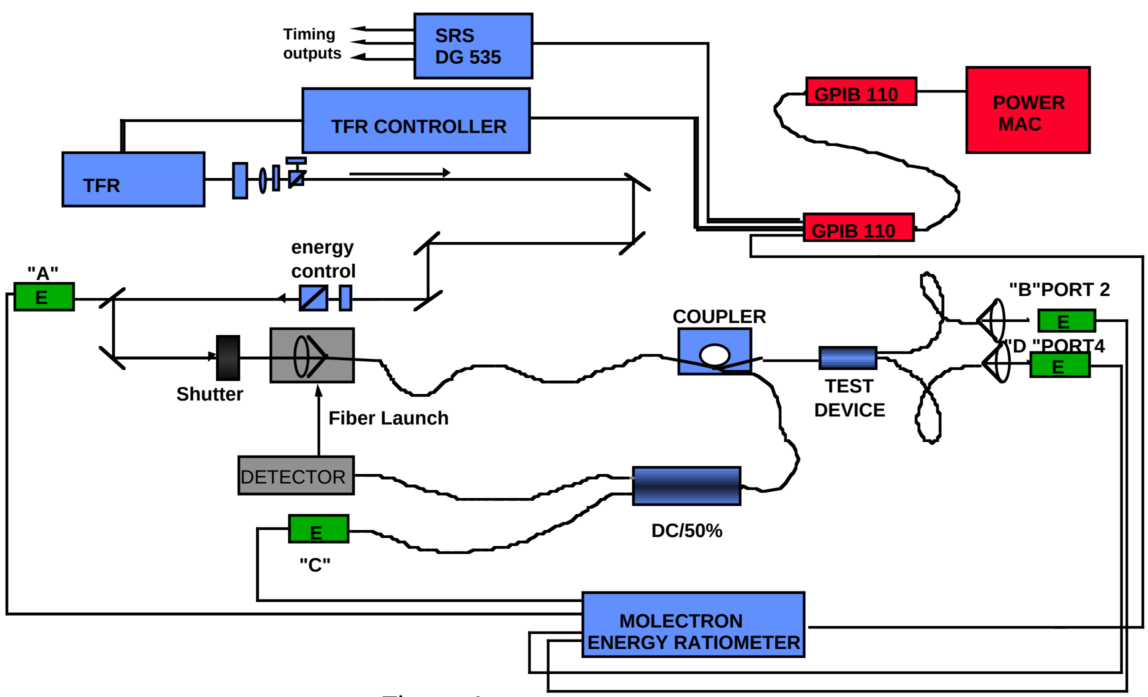


Figure 4

Energy measurements are made at several key locations. Detector A is calibrated to measure the input energy to the test component. Energy to the device is controlled by a 1/2 waveplate/polarizer pair. Detector C measures the energy in the single mode fiber prior to the test device. This detector is calibrated using a cutback technique described later. Detectors B and D measure the output energy. All of the energy data is acquired using a Macintosh platform with a GPIB interface to the energy ratiometer, TFR laser system, and timing system. The data acquisition software is a custom Labview program and all data is logged and written to a spreadsheet for analysis.

A typical damage run on a component takes approximately 1 hour. Starting at low energy, incremental increases in energy by a factor of 1.5 per step are made every 5 minutes until a target energy is reached. Data samples are taken every 10 seconds or 360 data samples per hour. An example of a data run is shown in figure 5 where the component is a dual Mach-Zender amplitude modulator. The graph shows measured energies at the input fiber face, fiber coupled energy, and output energy. The chart below the graph is a summery of the run, listing the target energy, measured maximum energies, and calculated maximum average power and fluence.

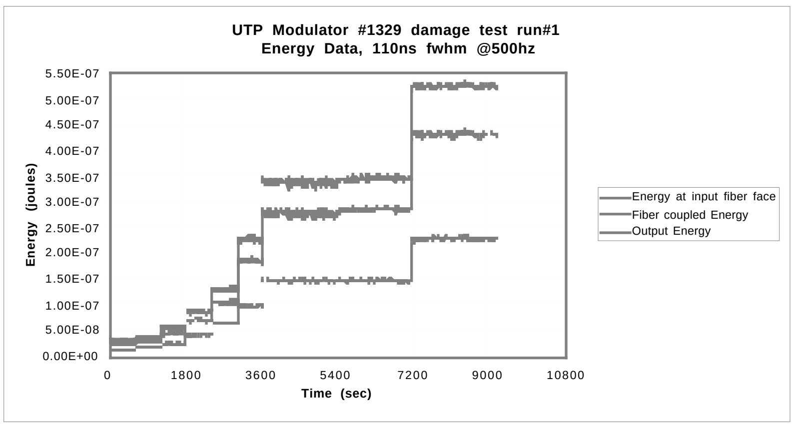


Figure 5

	Input Data				Output Data	
Component	NIF Target Energy (joules)	Energy Joules	Fluence joules/cm2	Average power(watts)	Energy (joules)	Fluence (joules/cm2)
UTP Mod #2	3.30E-07	4.30E-07	2.2346601	0.000215	2.30E-07	1.19528331

Chart 5

Establishing the test energy level or target energy for each NIF component was done using the following criteria. The NIF pulse length will be 30 nanoseconds, but our test pulse length is 120 nanoseconds or 4 times greater. Worst case scaling is the energy damage threshold increases as the square of the pulse length, in our case that’s a factor of 2. Also, we want to stress the component at a factor of 2 margin above its operating point so the maximum applied energy or target energy will be a factor of 4 above the NIF MOR operating energies calculated from the peak power curve (figure 2).

After a damage run has been completed, a cutback measurement run is made to measure the fiber coupling efficiency and calibrate the ”in” fiber energy diagnostic. The input fiber to the component is cut back, recleaved, and a run is made at the same energy step levels as the original component run to insure an accurate calibration. Figure 6a and 6b show a typical cut back run: 6a shows the energy measured at the fiber face and energy measured at the fiber output and 6b shows the coupling efficiency for the run.

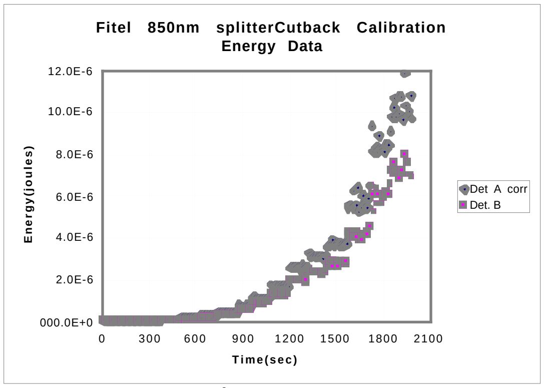


Figure 6a

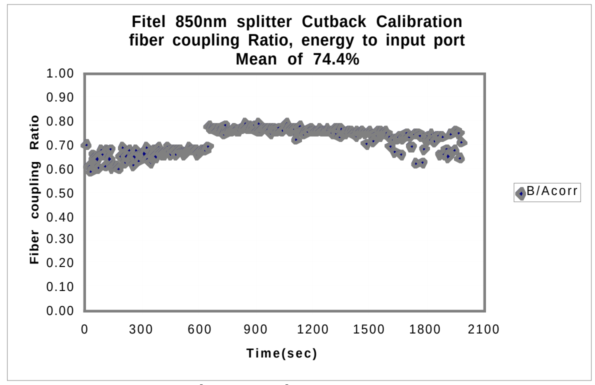


Figure 6b

4. COMPONENT TEST SUMMARY

Damage tests have been performed on a number of different components. Figure 7 shows a summary of the tests. The chart includes the target energy, measured maximum energies, and calculated maximum average power and fluence. The individual component results are now described.

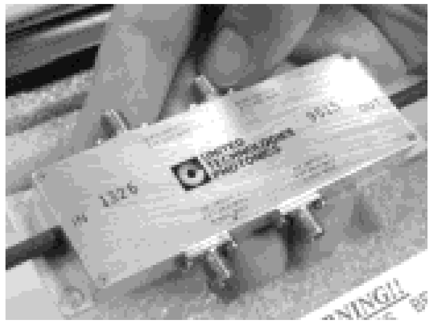
The first component, a polarization maintaining, multilayer dielectric splitter designed for a 50% split at 850nm was tested. This device is a similar design to the pump/signal multiplexers used in our fiber oscillator and fiber amplifier designs. A similar device might also be used as a 4-way splitter. The splitter was first tested for polarization stability and results show excellent PM stability with >20 db extinction ratio maintained at both output ports. The damage results are mixed with the input port surviving all the way up to the maximum energy with no damage. The output transmitted port also survived, however the output reflective port damaged at a low energy.

Two 1x4 silica-on-silicon splitters were tested: the first splitter had epoxy at the fiber/waveguide interfaces and the data shows that the input interface damaged at a low energy. The vendor verified that the damage was to the epoxy. A second splitter, a high power device that was manufactured with no epoxy in the active area of the interfaces was tested and the splitter survived at high energy. Polarization extinction ratio measurements were made to both splitters. The output ports averaged ~12db extinction minimum which meets the vendors best effort, however this falls short of our requirement of >20db extinction.

An FC-APC(angled physical contact) connector pair was tested. The connector pair was tested to the maximum energy with no damage sustained. The connectors were disconnected and reconnected “hot” five times with no damage or changes in insertion loss. This connector type will be used at the subcomponent level through out the system design.

An old prototype dual Mach-Zender amplitude modulator was tested as a precursor to the more expensive NIF type devices. Low power tests were made to measure the damage threshold and changes in transmission due to non linear effects. Extinction ratios of the individual Mach-Zenders were measured at various energy levels during the run, with no damage, and very small effects on transmission observed. High power runs were then made with wild fluctuations in the transmission observed above one milliwatt of average power. Transmission through the device decreased with increasing energy, not fully recoverable with bias adjustment, but reversible with a long time constant. This long time constant could indicate photorefractive effects changing waveguiding. This effect is likely due to average power and further understanding will be pursued with CW experiments.

A NIF type dual Mach-Zender amplitude modulator was tested. Results show no damage or change in transmission. Extinction measurements of the individual Mach-Zenders were made at different energy levels with no change over the entire run. The average power at the target energy is well below the level where instabilities were observed with the prototype modulator.



An example of the NIF type modulator
There are two modulators optically in series, to increase contrast and provide for separate “shaper” and “slicer” functions

Component, Energy and Power Data								
Component	Input Data NIF Target Energy (J)	Energy (J)	Fluence J/cm2	Average power (W)	Output Data Tport Energy(J)	Rport Energy(J)	Tport Fluence J/cm2	Rport Fluence J/cm2
850nmSplitte	2.75E-06	8.40E-6	43.65	0.0042	4.40E-06	3.40E-07	22.87	1.77
					Port 2 Energy(J)	Port 4 Energy(J)	Port 2 Fluence J/cm2	Port 4 Fluence J/cm2
1x4 splitter W/E	2.75E-06	1.00E-06	5.20	0.0005	1.75E-07	1.60E-07	0.91	0.83
1x4 splitterWo/E	2.75E-06	4.40E-06	22.87	0.0022	8.40E-07	9.00E-07	4.36	4.68
					Energy(J)	Fluence J/cm2		
FC connector	4.00E-07	3.20E-06	16.63	0.0016	2.70E-06	14.03		
Proto. modulator	3.30E-07	6.80E-06	35.34	0.0034	3.90E-07	2.03		
NIF modulator	3.30E-07	4.30E-07	2.23	0.0002	2.30E-07	1.20		

Figure 7

5. CONCLUSIONS

Epoxy Junctions: The epoxy fiber/chip or fiber/lens junctions of the components sometimes survive high fluence and sometimes fail. Manufacturers have said that their CW damage tests are similar and damage thresholds depend on contaminants and particulates in manufacturing. We can specify high damage threshold epoxied components and the manufacturers will have to improve their process and testing which would potentially raise cost. Alternatively, we can specify components without epoxy and the manufacturer can develop a different attachment technique (as with the high power 1 x 4 splitters) which would also raises the cost per unit.

Splitters: The 50/50 splitter has good polarization maintaining capability, but poor high energy performance. High energy performance could be improved with better contamination control in the manufacturing process, or by eliminating the epoxy interface in the device all together. The 1 x 4 silica-on-silicon splitter is inexpensive for a 4x split, and can be made very robust, but has poor polarization handling due to stress birefringence in the optical chip as a result of the manufacturing process. There are other integrated optic or fiber optic splitter technologies, which trade off performance and cost differently such as: diffused glass waveguides, or fused fiber directional couplers. We are pursuing these alternatives.

Modulators: The tests show that the modulators with epoxy interfaces can survive at the required NIF energy levels, however, we know that the epoxy can be a problem at low energy levels. The rest of our modulators will have to be tested to get some statistics on manufacturing consistencies and quality. The NIF modulators will have to specified to have a certain damage threshold and testing will be required at a factor of 2 above operating levels.

Data that has been presented shows that components in the NIF MOR laser system design can survive at the required energy levels. The epoxy to chip interface has been identified as the major damage area with these components. Manufacturers must improve techniques to increase damage thresholds at theses interfaces.